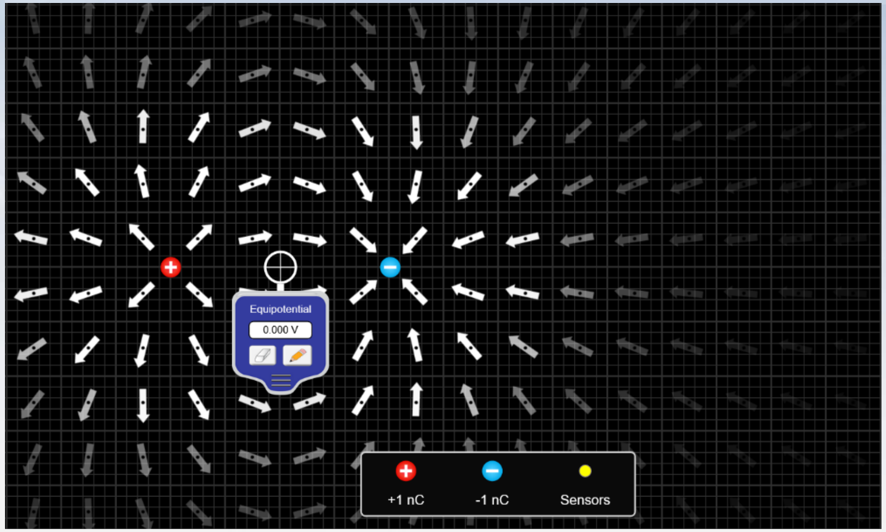
Y13 Electric Fields

Deflection Tube & Equipotentials

Outline for today's lesson

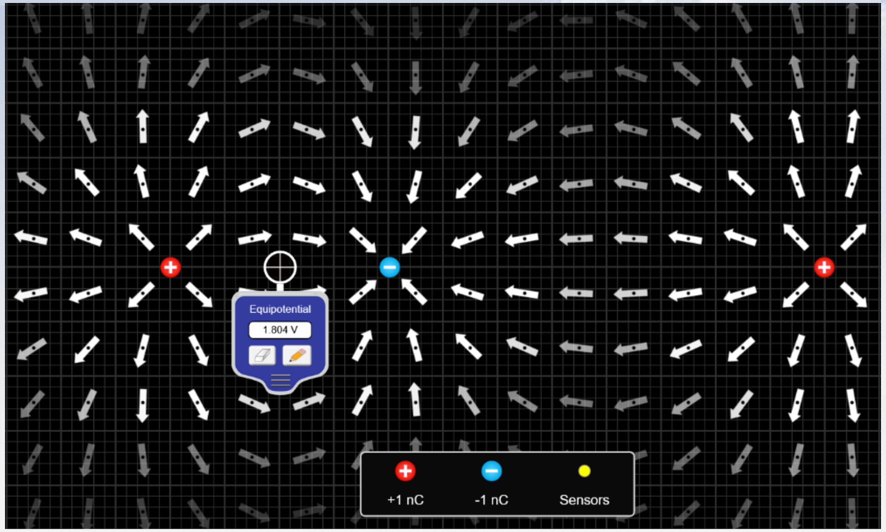
- Review the net potential due to multiple charges
- Observe the operation of an electron deflection tube
- Follow an analysis of electron deflection (worked example)
- Equipotential surfaces for radial and uniform electric fields

Potential due to multiple charges



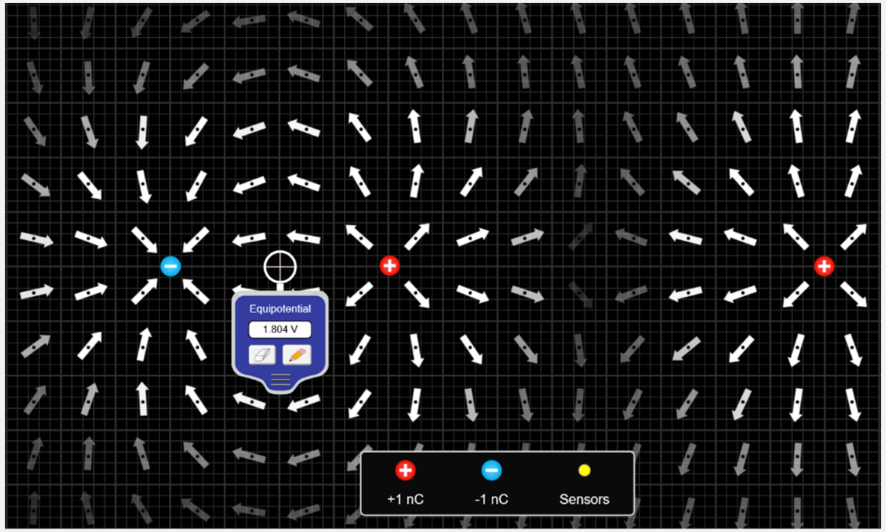
The potential at the midpoint between positive and negative charges of equal magnitude is zero.

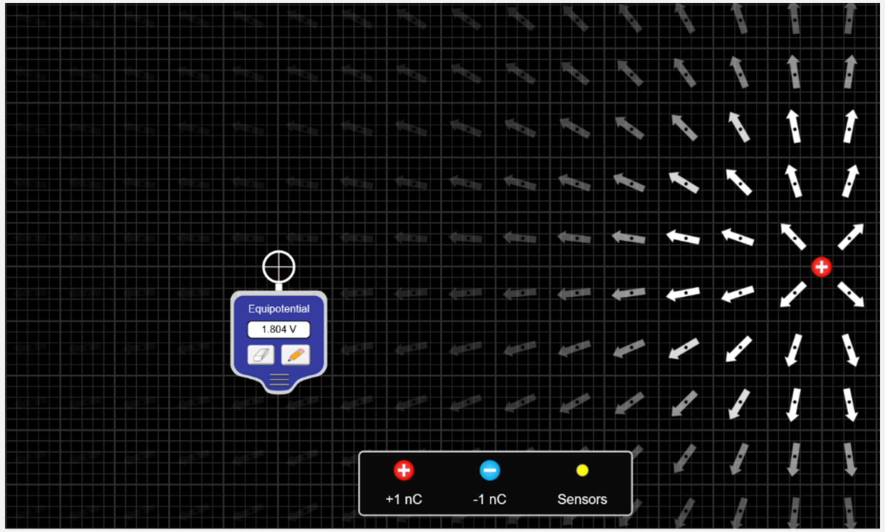
Adding a new charge drives the zero value to a new potential.



If the original charges are now swapped, what will the new value of the midpoint potential?

What will be the value of the midpoint potential when the two original charges are removed?





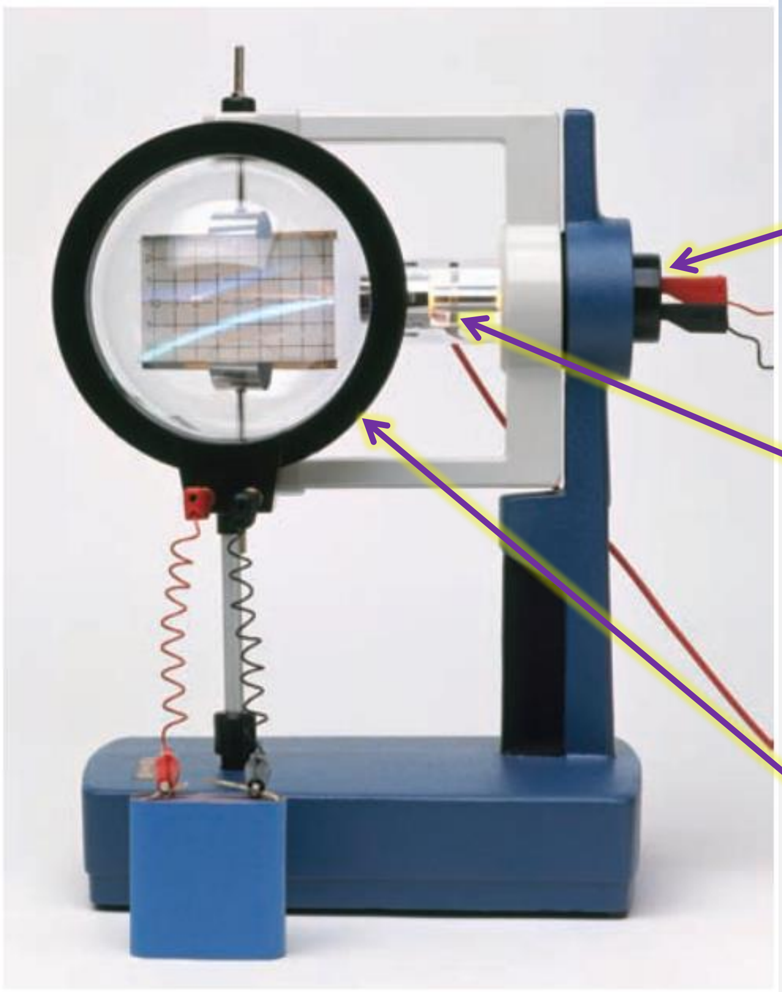
Screenshots created using https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_all.html

Electron deflection

Electrons are particles that have both mass and charge so they are affected by;

- gravitational fields
- electric fields
- magnetic fields

It is difficult to demonstrate the effect of gravitational fields because the force is so weak but the effects of electric and magnetic fields can be seen in the lab.



In the apparatus shown here, electrons are emitted from a small wire coil that is heated using a low-voltage current on the right of the tube.
The electrons are accelerated (with an EHT voltage) towards a target that has a circular aperture.
The resulting beam would travel horizontally across the grid-screen were it not for a magnetic field that has been created by passing a current through the large external coil. The same effect can also be produced using an electric field created inside the tube.

The electrons' path through the vertical electric field is a parabola. **Why?**

Deflection tube analysis (worked example)

Electron beam tube

This example refers to Figure 5.12. In an experiment, a beam of electrons is directed along the line PQ. The electrons arrive at P with a velocity of $4.0 \times 10^7\,\mathrm{m\,s^{-1}}$ travelling in the direction PQ. The squares on the grid measure 1 cm × 1 cm.

1 Calculate the time taken for the electrons to travel from P to Q.

Answer

$$d = v \times t$$

$$t = \frac{d}{v}$$

$$= \frac{0.1\,\mathrm{m}}{4.0 \times 10^7\,\mathrm{s}}$$

$$= 2.5 \times 10^{-9}\,\mathrm{s}$$

Now a potential difference of 2200 V is applied between A and B, so that the beam deflects upwards.

2 Calculate the acceleration of an electron in this electric field.

Answer

The electric field strength is

$$E = \frac{V}{d}$$

$$= \frac{2200\,\mathrm{V}}{0.06\,\mathrm{m}}$$

$$= 36.6\,\mathrm{kV\,m^{-1}}$$

The acceleration is given by

$$a = \frac{F}{m}$$

$$= \frac{EQ}{m}$$

where Q is the charge on an electron and m is its mass. This gives

$$a = \frac{3.66 \times 10^4\,\mathrm{V\,m^{-1}} \times 1.6 \times 10^{-19}\,\mathrm{C}}{9.1 \times 10^{-31}\,\mathrm{kg}}$$

$$= 6.4 \times 10^{15}\,\mathrm{m\,s^{-2}}$$

3 Show that the electron beam is deflected upwards to point R, which is about 2 cm above point Q.

Answer

To calculate the upwards displacement of the beam, we use the equation of motion:

$$s = ut + \frac{1}{2}at^2 = \frac{1}{2}at^2$$

since the initial upward velocity u = 0. So

$$s = \left(\frac{1}{2} \times 6.4 \times 10^{15}\,\mathrm{m\,s^{-2}}\right) \times (2.5 \times 10^{-9}\,\mathrm{s})^2$$

$$= 0.02\,\mathrm{m} \text{ or } 2\,\mathrm{cm}$$

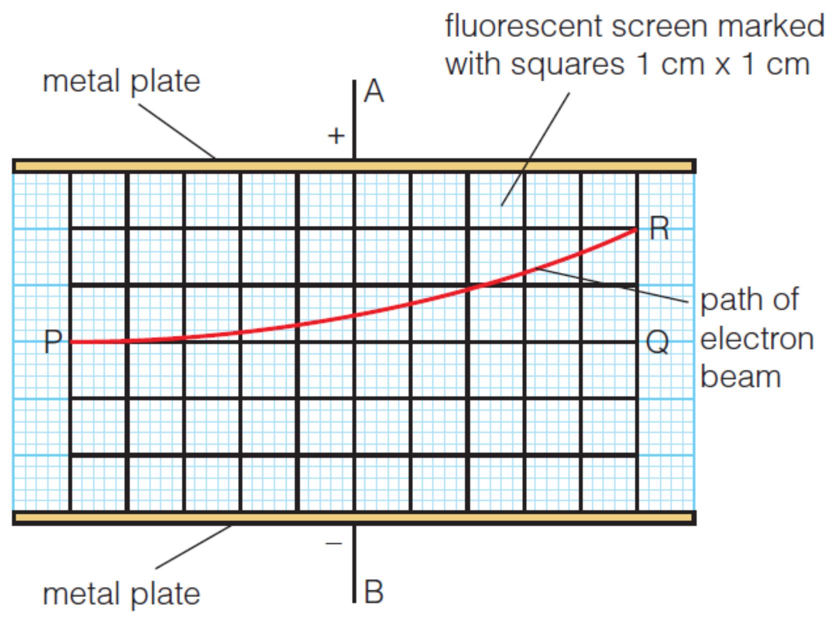


Figure 5.12

This worked example is in your textbook. You need to be confident in your ability to apply the method shown to answer examination (and homework) questions.

Equipotential surfaces

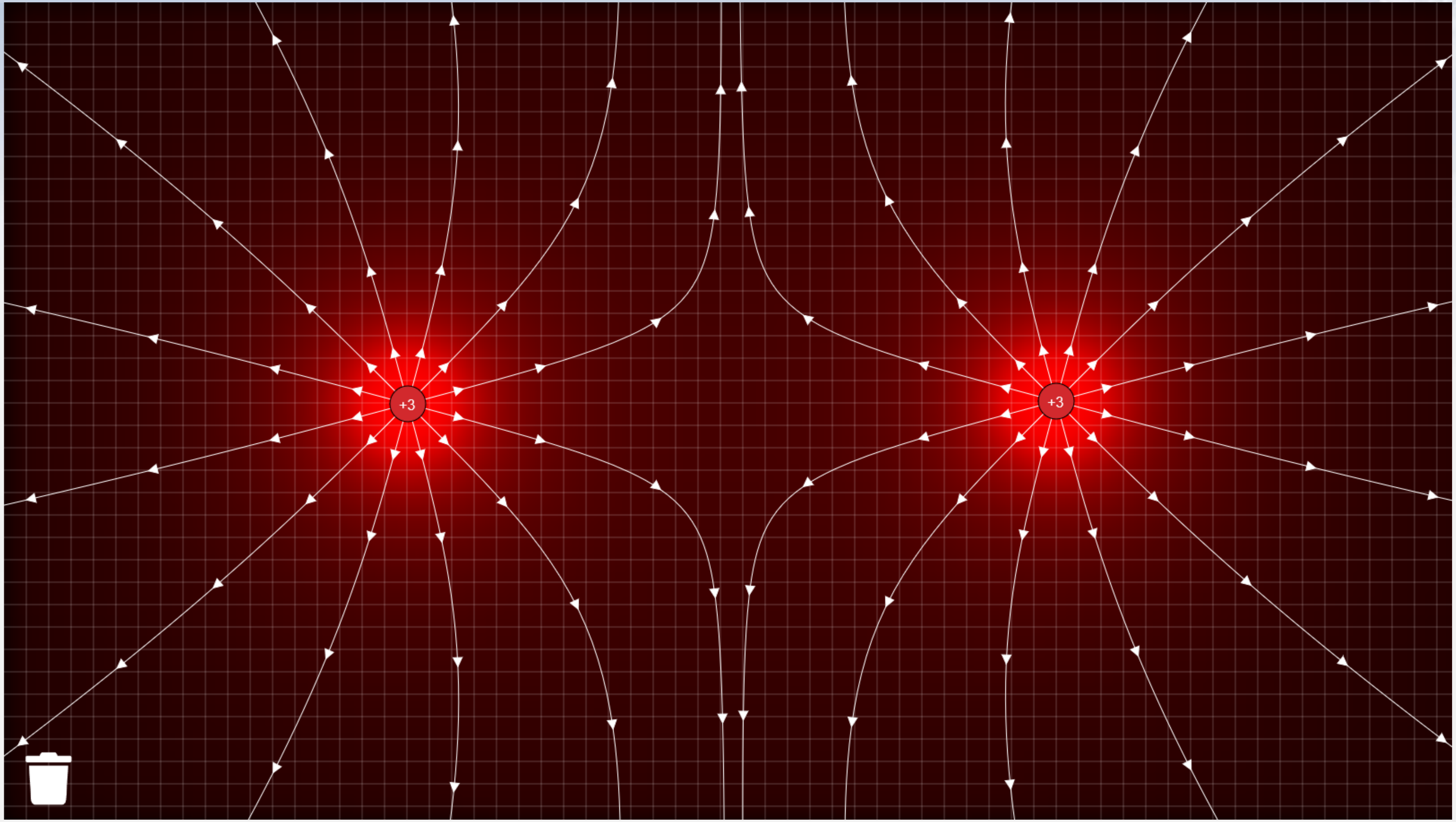
Given that the potential around a charged sphere falls off inversely with distance, it follows that for any value of **r** there will be a spherical surface where the potential has a fixed value. This is known as an equipotential surface.

If surfaces are chosen with equal increments of potential then the surfaces will have greater spacing as the distance from the charged sphere increases – and vice versa.

The work done (transfer of energy) when approaching or moving away from a charged sphere depends on the change in potential between the start and finish points. Therefore, if a charge moves along an equipotential surface the work done will be zero.

Lets look at an interactive animation to explore these facts…

Simulation of the field around a charged sphere



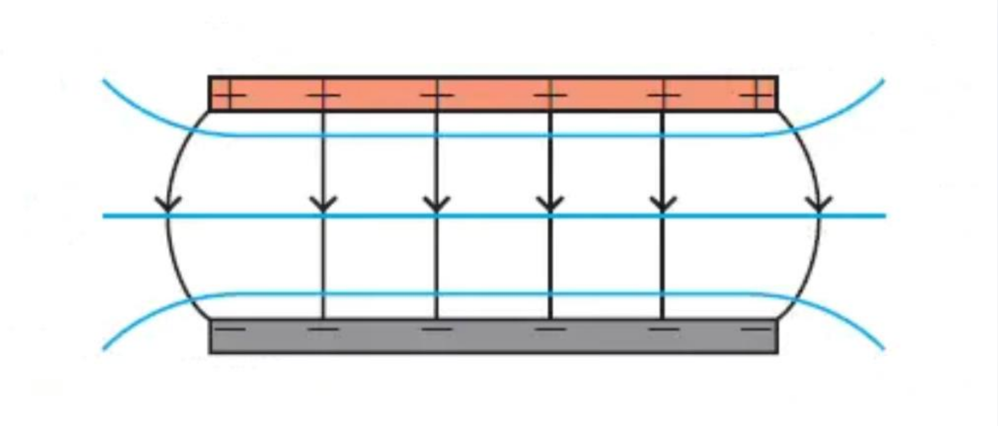
Source: https://icphysweb.z13.web.core.windows.net/simulation.html

Equipotential surfaces between parallel plates

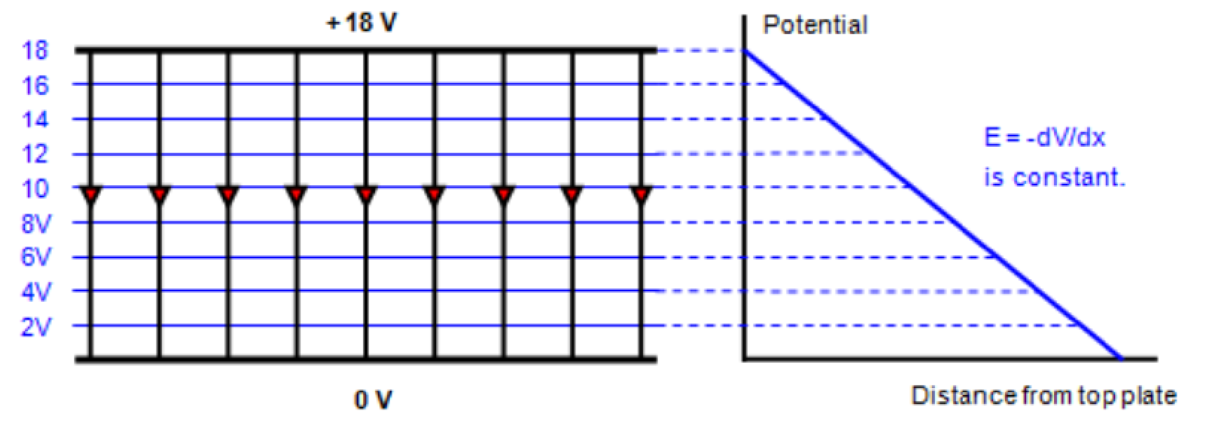
A lines (surface) that is parallel to the plates has a constant distance from both plates and therefore has a fixed potential.

These lines are known as equipotentials.

The equipotentials are parallel within the region bounded by the plates but curve beyond that region.



The value of each equipotential is proportional to its distance from the two plates. This must be true because the electric field is uniform and is defined as the potential gradient, as shown in the graph on the right. Note the negative sign, which indicates that the potential increases in the opposite direction to the field vector. Note also that the equipotentials are perpendicular to field lines.



Sources: https://www.schoolphysics.co.uk/age16-19/Electricity%2520and%2520magnetism/Electrostatics/text/Equipotentials_/index.html and https://physicsteacher.in/2022/03/16/equipotentials-between-two-oppositely-charged-parallel-plates-explanation/

Have we done all of this today?

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- Observe the operation of an electron deflection tube
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